

Catalytic hydration of ethylene oxide may use smaller amounts of water and can be carried out at lower temperatures and pressures. There are numerous examples of catalysts for hydration of an alkylene oxide to alkylene glycol.

5 U.S. Patent no. 5,260,495 discloses a process for producing monoalkylene glycol with a metalate-substituted hydrotalcite composition in which an anionic clay of metal oxide/hydroxide layers with large organic anion interstitial spacers has some of these spacers replaced with a metalate anion.

10 U.S. Patent no. 5,874,653 discloses a process for preparing an alkylene glycol by reaction alkylene oxide with water in the presence of a catalyst of a polymeric organosiloxane ammonium salt as an ion exchange resin catalyst.

U.S. Patent no. 4,967,018 discloses a process for catalytic
15 hydrolysis or alkylene oxide to alkylene glycol with a mixed metal framework catalyst of a divalent metal cation, such as magnesium, calcium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, palladium, platinum, copper, zinc, cadmium, mercury, tin and lead; a trivalent metal cation, such as aluminum, antimony,
20 titanium, scandium, bismuth, vanadium, yttrium, chromium, iron, manganese, cobalt, ruthenium, nickel, gold, gallium, thallium and cerium; and an anion, such as halide, nitrite, nitrate, sulfite, sulfate, sulfonate, carbonate, chromate, cyanate, phosphite, phosphate, molybdocyanate, bicarbonate, hydroxide, arsenate,

chlorate, ferrocyanide, borate, cyanide, cyanaurate, cyanaurite, ferricyanide, selenate, tellurate, bisulfate, oxalate, acetate, hexanoate, sebacate, formate, benzoate, malonate, lactate, oleate, salicylate, stearate, citrate, tartrate and maleate.

5 U.S. Patent no. 5,488,184 discloses a process for preparation of alkylene glycols by reacting an alkylene oxide with water in the presence of a catalyst of a solid material having electropositive sites, such as silica, silica-alumina, clay, zeolite and ion-exchange resin, coordinated with an anion, such as
10 bicarbonate, bisulfite, phosphate and carboxylate.

U.S. Patent no. 6,187,972 discloses a process for producing an alkylene glycol from an alkylene oxide and carbon dioxide via the intermediate formation of ethylene carbonate with a catalyst of an alkali metal bromide or iodide, an alkaline earth metal
15 bromide or iodide, an ammonium halide, such as tributyl methylammonium iodide, or a phosphonium halide, such as tributylmethylphosphonium iodide.

U.S. Patent no. 4,307,256 discloses a process for producing alkylene glycols from alkylene oxides, water and carbon dioxide in
20 the presence of an organic base catalyst, such as triethylamine, dimethylaniline and pyridine.

An acceptable hydration catalyst would have high selectivity to the monoalkylene glycol and a decrease in the amount of water required in comparison with a non-catalytic process. However,

prior art catalysts can have problems which make their use disadvantageous. Soluble acid catalysts have corrosion problems.

Alkaline catalysts have lower selectivity to MEG. Alkali metal or ammonium halides have lower solubility and are likely to precipitate which causes scaling and corrosion problems. Amine-based catalyst can have a strong, undesirable odor which can cause quality problems with the product. Ion exchange resins can result in metallate salts in the glycol product or can require long residence times. The ion exchange resins may also swell during the reaction and have limited tolerance to heat.

Ordinary Lewis acid catalysts are water sensitive and can be hydrolyzed by water. However, some Lewis acids, such as rare earth (lanthanide) triflates, are water tolerant and can be used in a variety of chemical reactions.

Indium triflate is used with lithium perchlorate in the catalytic acylation of aromatics to aromatic ketones ("Indium triflate: An Efficient Catalyst for the Friedel-Crafts Acylation of Aromatics", Christopher G. Frost and Joseph P. Hartley, Fourth International Electronic Conference on Synthetic Organic Chemistry (ECSOC-4), August 3, 2000).

Bismuth triflate is used for acylation of aromatics and alcohols and the sulphonation of aromatics ("Bismuth(III) Chloride and Triflate - Novel Catalysts for Arylation and Sulphonation Reactions - Review", Le Roux C et al, SynLett, 2002, 181).

U.S. 6,444,857 discloses reacting an alcohol with a diol derivative in the presence of an acid catalyst, such as scandium triflate, to form an intermediate in a process for producing Vitamin A.

5 U.S. 6,362,375 discloses metal triflate catalysts to catalyze a reaction between carboxylic acid and an aromatic in the presence of a volatile organic compound which forms an azeotrope with water, such as toluene, to produce aryl ketones.

10 U.S. 6,352,954 discloses a Lewis acid, such as scandium triflate, encapsulated in a network of polymer gel which can be used in a variety of organic syntheses, such as imino-aldo condensation, Mannich-type reactions, Michael reactions and Friedel-crafts reactions.

15 U.S. Patent no. 6,348,631 discloses acylation or sulphonation of aromatics to aromatic ketones or sulphones with a Lewis acid, such as a rare earth triflate.

20 U.S. Patent no. 6,194,580 discloses forming esters of tertiary alcohols by reacting a compound containing a tertiary alcohol with a acyl heteroaromatic ion-based compound in the presence of a lanthanide metal based catalyst such as scandium triflate.

U.S. Patent no. 6,111,135 discloses reacting ethylene, paraformaldehyde, formic acid and scandium triflate to form 1,3 propanediol diformate ester.

U.S. Patent no. 6,040,484 discloses hydroxylation of phenolic compounds with hydrogen peroxide with scandium triflate.

U.S. Patent no. 5,990,264 discloses copolymerization of tetrahydrofuran with cyclic carboxylic anhydride with scandium triflate.

U.S. Patent no. 5,948,696 discloses an aldol reaction of treating a resin-bound aldehyde or its imine with silyl enol ether in the presence of scandium triflate in dichloromethane.

U.S. Patent no. 5,770,678 discloses polymerization of cyclic ether, such as tetrahydrofuran, using metal compounds, such as scandium triflate and acetyl chloride or acetic anhydride.

U.S. Patent no. 5,728,901 discloses a process for nitrating an arene with nitric acid in the presence of a catalyst, such as scandium triflate.

U.S. Patent no. 4,543,430 discloses a process for the preparation of addition products of epoxides and hydroxylated compounds in the presence of a catalyst of a salt of trifluoromethanesulphonic acid, such as a triflate of an alkali (Group I) metal, an alkaline earth (Group II) metal or heavy metal. The examples used aluminum triflate as the preferred catalyst. Lithium triflate was also disclosed as a catalyst.

It would be advantageous to have a catalyst for hydration of an alkylene oxide to the corresponding alkylene glycol without the disadvantages of prior art catalysts.

SUMMARY OF THE INVENTION

This invention concerns preparation of alkylene glycols from the corresponding alkylene oxides in the presence of water and a catalyst containing water tolerant Lewis acids, such as metal salts of general formula MA_x wherein A is a non-coordinating or weakly coordinating anion and M is a metal with x being the valence of M. Optionally, carbon oxide may also be present. Examples of the metal include Group IIIB, rare earth or lanthanides, actinides and Group IVB. Examples of a non-coordinating or weakly coordinating anion are perfluoroalkylsulfonate, fluoralkylsulfonate and hexafluorophosphate ($[PF_6]^-$). Examples of perfluoroalkylsulfonates are trifluoromethanesulfonates ($[CF_3SO_3]^-$), also known as triflates. Examples of water tolerant Lewis acids are scandium triflate, europium triflate, hafnium triflate, yttrium triflate, lanthanum triflate and ytterbium triflate.

This invention relates in part to water tolerant Lewis acids in which the anion is non-coordinating or weakly coordinating. However, it has also been found that water tolerant Lewis acids in which the anion is coordinating, i.e., the anion is bound to the metal in an aqueous solution, are effective as catalysts for preparation of alkylene glycols from the corresponding alkylene

oxides. Similar to those catalysts with a non-coordinating or weakly coordinating anion, catalysts of the formula $M'B_x$ wherein M' is a metal, B is a coordinating anion and x is the valence of M' can have a Group IIIB, rare earth or lanthanide, actinide or Group IVB cation. Examples of coordinating anions are sulfate, chloride, acetate and nitrate. Specific water tolerant Lewis acids in which the anion is coordinating are scandium sulfate $[Sc_2(SO_4)_3]$, scandium chloride $[ScCl_3]$, scandium acetate $[Sc(OAc)_3]$ and scandium nitrate $[Sc(NO_3)_3]$. While such catalysts are effective in the preparation of alkylene glycols from the corresponding alkylene oxides, the conversion and reaction time are typically not as advantageous as that for water tolerant Lewis acids in which the anion is non-coordinating or weakly coordinating.

It is expected that water tolerant Lewis acids which contain both a non-coordinating or weakly coordinating anion and a coordinating anion would be effective as catalysts for preparation of alkylene glycols from the corresponding alkylene oxides. Similar to those catalysts with a non-coordinating or weakly coordinating anion, catalysts of the formula $M''A_xB_y$ wherein M'' is a metal, A is a non-coordinating or weakly coordinating anion, B is a coordinating anion and $x+y$ equals the valence of M'' can have a Group IIIB, rare earth or lanthanide, actinide or Group IVB cation. Specific water tolerant Lewis acids which contain both

non-coordinating or weakly coordinating anions and coordinating anions are scandium triflate sulfate $[\text{Sc}(\text{CF}_3\text{SO}_3)(\text{SO}_4)]$, scandium triflate chloride $[\text{Sc}(\text{CF}_3\text{SO}_3)_2\text{Cl}]$, scandium triflate acetate $[\text{Sc}(\text{CF}_3\text{SO}_3)_2(\text{OAc})]$ and scandium triflate nitrate $[\text{Sc}(\text{CF}_3\text{SO}_3)_2(\text{NO}_3)]$. While such catalysts should be effective in the preparation of alkylene glycols from the corresponding alkylene oxides, the conversion and reaction time would not be expected to be as advantageous as that for water tolerant Lewis acids in which the anion is non-coordinating or weakly coordinating.

DETAILED DESCRIPTION OF THE INVENTION

Alkylene glycols can be obtained by reacting the corresponding alkylene oxide with water in the presence of a catalyst. Carbon dioxide may be added to the reaction medium to improve selectivity to the glycol.

Alkylene oxides are generally of the formula $\text{R}^1\text{R}^2(\text{COC})\text{R}^3\text{R}^4$, where each R^1 , R^2 , R^3 and R^4 is independently hydrogen or an alkyl of from 1 to 10 carbon atoms. Examples of alkylene oxides are ethylene oxide, propylene oxide and butylene oxide. The corresponding alkylene glycol is generally of the formula $\text{R}^1\text{R}^2(\text{COHCOH})\text{R}^3\text{R}^4$, where R^1 , R^2 , R^3 and R^4 are as defined above, and may be obtained by hydration of the alkylene oxide, i.e., reacting it with water to introduce a hydroxyl group and

hydrogenate or protonate the oxygen. A mixture of glycols is formed (monoalkylene glycol, dialkylene glycol and higher alkylene glycols).

Though the reaction of alkylene oxide and water to alkylene glycol proceeds non-catalytically, improvements in reaction rate, selectivity and/or reduced water can be realized by the use of catalysts. The catalysts of the present invention are water tolerant Lewis acids, such as a metal salt catalyst of general formula MA_x wherein A is a non-coordinating or weakly coordinating anion and M is a Group IIIB, rare earth or lanthanide, actinide or Group IVB cation with x being the valence of M. By the term "water-tolerant" it is meant that the Lewis acid is not hydrolyzed by water. By the term "non-coordinating or weakly coordinating anion" it is meant that the anion is not bound to the metal in an aqueous solution. Examples of a non-coordinating or weakly coordinating anion in the present inventions are trifluoromethane sulfonate, also known as triflate ($[CF_3SO_3]^-$), hexafluorophosphate ($[PF_6]^-$), $[Al[OC(CF_3)_3]_4]^-$, tetrafluoroborate ($[BF_4]^-$), perchlorate ($[ClO_4]^-$), teflate ($[TeOF_5]^-$), BArF ($[B(ArH_xF_y)_4]^-$ where Ar is an aryl and $x+y=5$, e.g., $[B(C_6F_5)_4]^-$, tosylate ($[CH_3C_6H_4SO_3]^-$), mesylate ($[CH_3SO_3]^-$) and antimonyhexafluoride ($[SbF_6]^-$). Further examples of non-coordinating or weakly coordinating anions are found in "The Search for Larger and More Weakly Coordinating Anions", Steven H. Strauss, Chem. Rev. vol. 93, p. 927-942 (1993) and

"Structure and Characterization of $\text{Cl}_3^+[\text{Al}\{\text{OC}(\text{CF}_3)_3\}]^-$; Lewis Acidities of CX_3^+ and BX_3 ", Ingo Krossing et al., Angew. Chem. Int. Ed., vol. 42, p. 1531-1534 (2003), which are incorporated by reference.

5 It should be noted that whether a particular anion is "non-coordinating or weakly coordinating" is dependent on its environment, e.g., solvent, presence of impurities and, especially, the cation. For example, sodium chloride (NaCl) is completely dissociated in water and the chlorine anion would be a
10 non-coordinating or weakly coordinating anion; however, aluminum chloride (AlCl_3) in an aqueous solution would still have chloride ions bound to the metal and chloride would not be non-coordinating or weakly coordinating.

 Examples of Group IIIB metals are scandium and yttrium. An
15 example of Group IVB metal is hafnium. Examples of rare earth or lanthanide cation are lanthanum, europium and ytterbium. Examples of water tolerant Lewis acids in the present invention are scandium triflate [$\text{Sc}(\text{CF}_3\text{SO}_3)_3$], europium triflate [$\text{Eu}(\text{CF}_3\text{SO}_3)_3$], hafnium triflate [$\text{Hf}(\text{CF}_3\text{SO}_3)_4$], yttrium triflate [$\text{Y}(\text{CF}_3\text{SO}_3)_3$],
20 lanthanum triflate [$\text{La}(\text{CF}_3\text{SO}_3)_3$] and ytterbium triflate [$\text{Yb}(\text{CF}_3\text{SO}_3)_3$]. Many of these water tolerant Lewis acids are commercially available or can be synthesized by methods known in the art.

The catalysts of the present invention are typically homogeneous, i.e., liquid phase. The catalysts may be heterogenized using procedures known in the art. These procedures include the use of ion exchange resins, microencapsulation and
5 binding to a metal oxide surface.

In a process for preparing an alkylene glycol by reaction alkylene oxide with water in the presence of a catalyst of the present invention, a mixture of alkylene oxide and water in the liquid state is contacted with a catalyst containing a water
10 tolerant Lewis acid having a non-coordinating or weakly coordinating anion and a rare earth or lanthanide cation. The process is carried out at a temperature from about 20°C to 250°C, preferably 50°C to 200°C and a pressure greater than atmospheric, preferably 25 psig to 1000 psig with the temperature and pressure
15 selected to maintain liquid phase conditions. The molar ratio of alkylene oxide to water is in the range from about 5 to 25.

The invention having been generally described, the following examples are given as particular embodiments of the invention and to demonstrate the practice and advantages thereof. It is
20 understood that the examples are given by way of illustration and are not intended to limit the specification or the claims to follow in any manner.

EXAMPLE 1

Reaction of EO and water in the presence of triflates:

Example 1

A roundbottom flask was charged with 50 g of water (conductivity
5 18 mΩ) and chilled in an icebath. Ethylene oxide (EO) from
Aldrich was introduced to the solution by bubbling EO gas from a
lecture bottle through the solution. A total of 4.6 g of EO was
introduced to the vessel. A sample was taken from the solution
and analyzed by GC. The EO containing aqueous solution was
10 transferred to a different roundbottom flask, which had been
charged with 0.1404 g of scandium triflate [$\text{Sc}(\text{CF}_3\text{SO}_3)_3$] from
Aldrich. The mixture of EO, water and $\text{Sc}(\text{CF}_3\text{SO}_3)_3$ was quickly
transferred to a 100 mL autoclave. The reactor was pressurized
to 50 psig with N_2 and heated up to 100°C , which took about 8
15 minutes. A sample was taken once the reactor had reached the
target temperature and every 10 minutes thereafter to monitor the
progress of the reaction. The samples were analyzed by off-line
GC. During the initial heating ramp, 80% of the initial EO had
reacted and the reaction was complete after 10 minutes at
20 reaction temperature.

Example 2

The procedure of Example 1 was followed except 20 mg of
 $\text{Sc}(\text{CF}_3\text{SO}_3)_3$ was used. The reaction was complete after 60 minutes.

Example 3

The procedure of Example 1 was followed except the reaction temperature was set at 80°C. The reaction was complete in about
5 20 minutes at reaction temperature.

Example 4

The procedure of Example 1 was followed except 10 g of EO and 50 g of water were used, while keeping the $\text{Sc}(\text{CF}_3\text{SO}_3)_3$ amount at 0.14
10 g. Even with the increased amount of EO, the reaction was still complete after only 10 minutes at reaction temperature.

Example 5

The procedure of Example 1 was followed except 0.18 g of europium
15 triflate $[\text{Eu}(\text{CF}_3\text{SO}_3)_3]$ was used. About 85% conversion was observed after 60 minutes at reaction temperature.

Example 6

The procedure of Example 1 was followed except 0.251 g of hafnium
20 triflate $[\text{Hf}(\text{CF}_3\text{SO}_3)_4]$ was used. At the end of the heating ramp, all EO had already been converted.

Example 7

The procedure of Example 1 was followed except 0.17 g of yttrium triflate $[Y(CF_3SO_3)_3]$ was used. About 75% conversion was observed after 60 minutes at reaction temperature.

5

Example 8

The procedure of Example 1 was followed except 0.19 g of lanthanum triflate $[La(CF_3SO_3)_3]$ was used. About 78% conversion was observed after 60 minutes at reaction temperature.

10

Example 9

The procedure of Example 1 was followed except 0.192 g of ytterbium triflate $[Yb(CF_3SO_3)_3]$ was used. About 85% conversion was observed after 60 minutes at reaction temperature.

15

Reaction of EO and water in the presence of triflates (Group IIIA cation):

Comparative Example 1

The procedure of Example 1 was followed except 0.141 g of aluminum triflate $[Al(CF_3SO_3)_3]$ was used. About 100% conversion was observed after only 10 minutes at reaction temperature.

20

Comparative Example 2

A roundbottom flask was charged with 50 g of water (conductivity 18 mΩ) and 0.141 g of $\text{Al}(\text{CF}_3\text{SO}_3)_3$. The mixture of water and $\text{Al}(\text{CF}_3\text{SO}_3)_3$ was quickly transferred to a 100 mL autoclave. The reactor was pressurized to 50 psig with N_2 and heated up to 100°C. Once the mixture reached temperature, 4.6 g of EO was charged to the autoclave. A sample was taken 10 minutes after the EO was charged to the water catalyst mixture and analyzed by off-line GC. All EO had converted to glycols.

Reaction of EO and water in the presence of triflates (Group IA cation):

Comparative Example 3

The procedure of Example 1 was followed except 51 mg of lithium triflate $[\text{Li}(\text{CF}_3\text{SO}_3)_3]$ was used. About 73% conversion was observed after 60 minutes at reaction temperature.

Reaction of EO and water in the presence of sulfate (coordinating anion):

Comparative Example 4

The procedure of Example 1 was followed except 62 mg of scandium sulfate $[\text{Sc}_2(\text{SO}_4)_3]$ was used. Full conversion was observed after 60 minutes at reaction temperature.

Reaction of EO and water in the presence of chloride
(coordinating anion):

Comparative Example 5

- 5 The procedure of Example 1 was followed except 54 mg of scandium
chloride $[\text{ScCl}_3]$ was used. About 86% conversion was observed
after 60 minutes at reaction temperature.

10 Reaction of EO and water in the presence of acetate (coordinating
anion):

Comparative Example 6

The procedure of Example 1 was followed except 67 mg of scandium
acetate $[\text{Sc}(\text{OAc})_3]$ was used. About 96% conversion was observed
after 60 minutes at reaction temperature.

15

Reaction of EO and water in the presence of nitrate (coordinating
anion):

Comparative Example 7

- 20 The procedure of Example 1 was followed except 81 mg of scandium
nitrate $[\text{Sc}(\text{NO}_3)_3]$ was used. Almost complete conversion was
observed after 30 minutes at reaction temperature.

EO hydration in the absence of a catalyst:

Comparative Example 8

The procedure of Example 1 was followed except no catalyst was used. During the initial heating ramp, only 20% of the initial EO
5 had converted, and even after 3 hours at reaction temperature, not all EO had converted as indicated by GC analysis. Only 70% conversion was observed.

10 The examples above with a catalyst having a Group IIIB, rare earth or Group IVB metal cation and a non-coordinating or weakly coordinating anion demonstrate the benefit and advantages of the present invention. Examples 1-9 show better conversion to EO over a shorter period of time compared to Comparative Example 8 (non-
15 catalytic hydration). Examples 1-9 show conversion and reaction times that are at least as good as the prior art catalysts of Comparative Examples 1-3 (catalytic hydration with triflates and Group IA or Group IIIA cations). Examples 1-9 show conversion and reaction times that are better than the catalysts of Comparative
20 Examples 4-7 (catalytic hydration with a Group IIIB cation and coordinating anions). Comparative Examples 4-7 show conversion and reaction times that are better than Comparative Example 8 (non-catalytic hydration). Based on these data, it is expected that a catalyst containing both a non-coordinating or weakly coordinating

SERIAL NO. _____
VAN HAL, RAMPRASAD

PATENT APPLICATION
STC-01-0007

anion and a coordinating anion with a Group IIIB, rare earth or Group IVB metal cation would have better conversion and reaction time than that for non-catalytic hydration.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.